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ABSTRACT

This sixth in a series of six modules for a course titled Civil/Structural Inspection describes inspection activities associated with pre-stressed concrete such as reviewing material certifications and test reports, inspecting construction operations, performing materials testing, and preparing records and reports of inspection and testing activities. The module follows a typical format that includes the following sections: (1) introduction, (2) module prerequisites, (3) objectives, (4) notes to instructor/student, (5) subject matter, (6) materials needed, (7) procedures, (8) data table, (9) reference materials, (10) test. (The course is one of fifteen technical courses for the second year of a two-year postsecondary curriculum in Nuclear Quality Assurance/Quality Control Technology.) (LRA)

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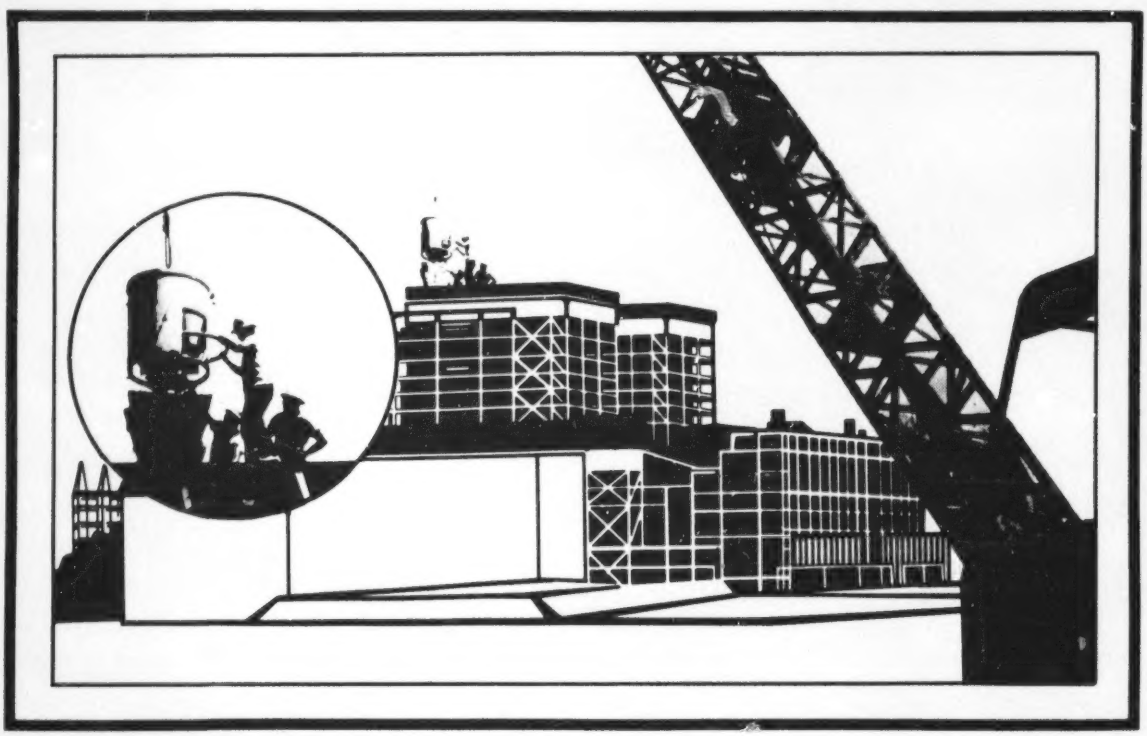
NUCLEAR TECHNOLOGY

COURSE 29 CIVIL/STRUCTURAL INSPECTION

MODULE 29-6 Pre-Stressed Concrete Materials, Fabrication and Inspection



CE 024 906

GENERAL PHYSICS CORPORATION
Columbia , Maryland

COURSE MODULES

COURSE 29 CIVIL/STRUCTURAL INSPECTION

Module 29-1	Inspection of Construction Operations
Module 29-2	Structural Steel Materials, Installation, and Inspection
Module 29-3	Concrete Materials
Module 29-4	Concrete Preparation, Production, Placement and Finishing
Module 29-5	Concrete Testing and Inspection
Module 29-6	Prestressed Concrete Materials, Fabrication, and Inspection

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This module was prepared for General Physics Corporation by Richard Groseclose, General Physics Corporation.

GENERAL PHYSICS CORPORATION

1979

INTRODUCTION

Inspection of activities associated with prestressed concrete is frequently performed by the trained QA/QC technician. In such a capacity, the technician is responsible for reviewing material certifications and test reports for acceptability, inspecting construction operations, performing materials testing, and preparing records and reports of inspection and testing activities.

Concrete is a universally available, relatively inexpensive, durable and easily molded construction material which is very strong in compression, and relatively weak in tension. Prestressing is a technique used to eliminate, or materially reduce, the tensile stresses normally encountered in structural concrete members. The technique involves introducing a compressive stress within the concrete member that will partially or wholly balance the tensile stresses that occur in service.

Prestressing is usually introduced in concrete by means of internal steel tendons which are stressed and then anchored. High-strength steel is currently the predominant material used for such tendons. Tendons are usually embedded in the concrete member, but can be external, as in a tie rod or a tied arch. Prestressing may also be applied by external force, such as by jacking applied at the crown of an arch or at the ends of a pavement slab.

High-quality steels and high-quality concretes are essential for producing stable pre-stressed members. The initial quality of the steel tendon is controlled by the steel manufacturer. The construction contractor is responsible for maintaining that condition by protecting it during construction operations; by proper installation, anchoring and stressing operations; and by the durability of the concrete encasement.

The concrete, which is controlled directly by the contractor, is the most critical and sensitive aspect of "prestressed concrete." The contractor controls the quality of the aggregates and water used, and the acceptance of cements and admixtures. The contractor also controls all fabrication activities: batching, mixing, transportation, form setting, tendon installation, concrete placement, consolidation and curing.

MODULE PREREQUISITES

The student/trainee should have prior training or experience in concrete materials; concrete preparation, products, placement, and finishing; and concrete testing and inspection. Completion of Nuclear Technology Modules 29-3, 29-4 and 29-5 satisfies this prerequisite.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. State the purpose of concrete prestressing.
2. Name three basic methods for prestressing concrete members and briefly describe how each method prestresses concrete members.
3. Describe the role of standards in ensuring quality of concrete materials.

4. Name three types of steel tendons used for pre- and post-tensioning.
5. State the purpose of tendon ducts.
6. Describe the techniques for pre-tensioning and post-tensioning concrete members including type of tendon, tendon installation, method of tensioning, use of reference marks, and release of tension.
7. Describe typical inspections associated with the following operations including at least two inspection attributes for each.
   a. setting of forms
   b. installation of tendons in pre-tensioned members
   c. anchoring and pre-tensioning of tendons
   d. concreting operations
   e. concrete curing and form removal
   f. de-tensioning of pre-tensioned tendons
   g. installation and post-tensioning of tendons
   h. grouting operations

SUBJECT MATTER

CODES AND STANDARDS

Standardization of methods and materials is an essential consideration for attaining the requisite quality, strength, and durability of prestressed concrete structural members. For most nuclear power plant applications, methods and standards developed by the Prestressed Concrete Institute (PCI) are incorporated in the plant specification requirements by the Architect-Engineer. Other types of construction may use standards developed by the American Association of State Highway Officials (AASHO), the American Railway Engineering Association (AREA), the American Concrete Pipe Association (ACPA), or the American Concrete Institute (ACI), as applicable.

The materials used are essentially portland cement concrete, reinforcing steel materials, and steel tensioning materials. The specifications for these materials usually require conformance to American Society of Testing and Materials (ASTM) and for American Concrete Institute (ACI) standards. The various materials used and the applicable standards are discussed later in this module in conjunction with descriptions of uses of materials.

CONCRETE PRESTRESSING METHODS

General

Concrete prestressing is a technique used to eliminate, or materially reduce, the tensile stresses normally encountered in structural concrete members. The technique involves introducing a compressive stress within the concrete member that will partially or wholly balance the tensile stresses which occur in service.

Prestressing is usually introduced in concrete by means of internal steel tendons which are stressed and then anchored. High-strength steel is currently the predominant material used for such tendons. Tendons are usually embedded in the concrete member, but can be external, as in a tie rod or a tied arch. Prestressing may also be applied by external force, such as by jacking applied at the crown of an arch or at the ends of a pavement slab. There are three basic methods for prestressing concrete structures. These are (1) post-tensioned concrete method, (2) pre-tensioned steel method, and (3) post-tensioned tendon method.

Post Tensioned Concrete Method

In the post-tensioned concrete method the concrete member is cast and hardened, and prestressed by jacking each end against abutments. No tendons or other components in tension are used. This method has had only limited use in this country, but has been used abroad in the design and construction of dams, drydocks and pavements.

Pre-Tensioned Steel Method

The pre-tensioned steel method employs steel wires or strands called tendons. The tendons are placed within the concrete form and pulled to prescribed tension between anchors prior to the placement of the concrete. While the tension is maintained, the concrete is placed and allowed to harden and bond firmly to the tendons. After the concrete attains its rated strength by curing the tendons are cut loose at the ends of the member. The tension in the tendons is transferred to the bonded concrete which compresses the concrete. Prestress is transferred only by elastic shortening of the concrete. Until the concrete has actually shortened, it is not prestressed.

The tendons used in pre-tensioned construction must be relatively small in diameter, since the bond stress between the concrete is relied upon to transfer the stress from the tendon to the concrete. A large number of small tendons are normally required to develop the required prestressing force.

Not all pre-tensioned tendon designs pass the tendon straight through the member. Instead, the member may be designed to have the tendon deflected or draped into a trajectory that approximates a curve. This technique is frequently used on large structural members, such as bridge guides and light roof slabs with integral beams.

The pre-tensioned steel method is most frequently used in permanent precasting plants, and has become a major method in this country.

Post-Tensioned Tendon Method

In the post-tensioned tendon method, the tendons are inserted through formed tubes or ducts in the concrete member after the concrete has been cast and hardened. Anchorages are then attached, and the tendons are tensioned against the concrete.

Accurate alignment of the anchorages, also called bearing plates, normal to the concrete is essential. These bearing plates must be accurately positioned and have complete bearing on the concrete beneath. In the fabrication process, the anchor plates are set in position in the ends of the concrete forms, and secured to prevent dislocation during the concreting operation.

The tendon passages through the concrete are formed either by inserting metal tubes or flexible metal hoses in the forms and concreting them into the structure, or by using inflatable rubber hoses or tubes which are removed

after the concrete has hardened. Such passages formed directly in the concrete are usually flushed thoroughly with fresh water before tendon installation to remove residual material which may be corrosive to the tendon steel.

After tendon installation and tensioning, the duct is pumped full of a grout mixture, filling all of the voids. The grout hardens and cures and serves two purposes. First, grout bonds the tendon to the concrete section. Secondly, grout provides a protective coating on the tendon steel to prevent corrosion.

This post tensioning method is used for both pre-cast and cast-in-place construction. It has wide-spread use in this country, and has been used for prestressing many concrete reactor building containment structures in nuclear power plants.

Pre-Tensioning vs. Post-Tensioning

Pre-tensioning is usually associated with operations at precasting plants, and post-tensioning is usually regarded as a method of prestressing concrete at the job site. However, post-tensioned beams and roof sections are often made in precasting plants and transported to the job site for later tensioning. Also, on large projects where many pre-tensioned members are to be utilized, the contractor may set up temporary pre-tensioning facilities for on-site production of pre-tensioned elements. Each method of making prestressed concrete has particular theoretical, practical, and economic advantages and disadvantages which are considered by the architect-engineer when the basic structural designs are developed. The role of the QA/QC technician is one of verifying that the specified method is in fact used and used correctly.

PRESTRESSED CONCRETE MATERIALS

General

High-quality steels and high-quality concretes are essential for producing stable pre-stressed members. The initial quality of the steel tendon is controlled by the steel manufacturer. The construction contractor is responsible for maintaining that condition by protecting it during construction operations; by proper installation, anchoring and stressing operations; and by the durability of the concrete encasement.

The concrete, which is controlled directly by the contractor, is the most critical and sensitive aspect of "prestressed concrete." The contractor controls the quality of the aggregates and water used, and the acceptance of cements and admixtures. The contractor also controls all fabrication activities: batching, mixing, transportation, form setting, tendon installation, concrete placement, consolidation and curing.

Concrete Materials

The materials used for prestressed concrete members are essentially the same as those normally used for structural concrete: aggregates, portland cement, admixtures and water. Prestressed concrete usually weighs from 140 to 160 pounds per cubic foot, and is batched for compressive strengths from 3500 to 7000 psi.

Aggregates are usually specified to be gravel or crushed rock. For normal high strength concrete for prestressed applications, gravel produces better workability and compactability at relatively low water/cement ratios. Crushed rock of proper angularity, however, is superior for extremely high-strength concrete, but requires intensive vibration to achieve proper compaction.

The maximum size of the coarse aggregate is normally limited, with the optimum size for most applications being about 3/4 inch. Fine aggregates may range from fines into the coarse sizes. The cement-rich mixtures employed in prestressed concrete provide ample cement-paste for complete particle coating and the filling of voids. Aggregates must be free from clay coatings or particles, which effectively increase shrinkage and decrease concrete strength, Also, aggregates must be free from salt. Salt contamination, even in small amounts, reduces the corrosion-inhibiting value of the cement, and causes electro-chemical corrosion of steel reinforcing elements.

Aggregates are usually selected and used in accordance with one or both of the following standards:

- American Society of Testing and Materials (ASTM) Standard C33, "Concrete Aggregates"
- American Concrete Institute (ACI) Title No. 58-24, "Selection and Use of Aggregates for Concrete"

Cements used in prestressed concrete are almost exclusively portland cement types. The types are:

- Type I - Standard
- Type II - Moderate low-alkali and salt resisting
- Type III - High early strength
- Type IV - Low heat of hydration
- Type V - Sulfate resisting

Types I and II cements are most frequently used, and are selected for an optimum combination of early strength, shrinkage, durability and economy. Type I is suitable for most building work, but Type II provides greater durability and corrosion protection for embedded steel in coastal and marine environments having salt-air and salt-fogs.

Type III is frequently used for precast members where rapid early strength is required and shrinkage can occur without restraint. Type III is usually not feasible for cast-in-place members, due to the excessive rate of shrinkage and resultant cracking that can occur in such a restrained configuration.

It is standard practice to require that all cements used for prestressed concrete work conform to ASTM standard C150. "Specification For Portland Cement".

Admixtures, or additives to the concrete mixture, are frequently used to obtain one or more of the following results:

- retain or improve workability while lowering the water/cement ratio
- retard initial set
- accelerate final set
- increase early strength
- reduce shrinkage

The admixtures generally used in prestressed concrete are types A or D, as defined in ASTM standard C494, "Standard Specification for Chemical Admixtures for Concrete." These materials consist of either lignosulfonates, organic acids, or polymers.

Many admixtures used in conventional concrete contain chlorides such as $CaCl_2$. Such admixtures must be prohibited from use in prestressed concrete; the chloride ion will attack prestressing tendons and result in stress corrosion and pitting. Admixtures, therefore, must be carefully selected, and employed judiciously.

The quality of the mixing water used in prestressed concrete must also be controlled for assuring proper set and maximum durability. In addition to being potable, the

amounts of included salt, silt and organic materials should be restricted. Typical limitations for these impurities are as follows:

- no impurities allowed that will cause a change in time of set greater than 25% nor a reduction in strength at 14 days age greater than 5% as compared with distilled water.
- chloride ion less than 650 parts per million
- sulfate ion less than 1300 parts per million
- water free from oil

Steel Materials

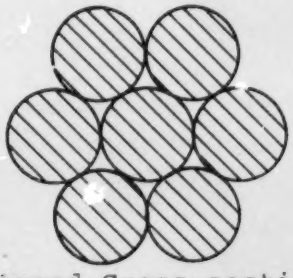
Steel tendons are the most widely used materials for inducing a compressive stress into a prestressed member. Tendons are usually located inside the concrete cross section, either directly embedded, or grouted in a formed duct or tube.

Tendons must have high tensile strength and the ability to withstand indefinitely a high state of stress, with little loss due to relaxation, corrosion, or fatigue. The most commonly used materials for tendons are cold-drawn stress-relieved steel wires, stress-relieved stranded wire, and high-tensile alloy steel bars.

Cold drawn wires are frequently used in post-tensioned construction, but rarely used in pre-tensioned members due to the relatively low bond strength between the concrete and the smooth wires. Cold drawn wires are manufactured in diameters of 0.192, 0.196, 0.250 and 0.276 inches to conform to the ASTM Standard A421, "Specification for Uncoated Stress-Relieved Wire for Prestressed Concrete."

Standard wire tendons of substantial strength are produced by weaving several wires into a strand. Seven-wire strand is widely used in pretensioning and, to a lesser extent, in post-tensioning. Seven wire strands are made by

twisting six wires around a slightly larger, straight central wire. After being twisted together, the strands are stress relieved, by heat treatment. Stranded tendons of this type are illustrated in Figure 29-6-1, and are fabricated to the requirements of ASTM Standard A416, "Specification for Uncoated Seven-Wire Stress-Relieved Strand for Prestressed Concrete."



Enlarged Cross-section of Typical Seven-wire Strand

Figure 29-6-1.

Alloy-steel bars are used extensively for post-tensioning tendons. These bars are made in standard nominal diameters from 1/2 to 1 3/8 inch from an alloy steel conforming to ASTM Standard A322, "Standard Specification for Hot-Rolled Alloy Steel Bars." The bars are cold stretched to raise the yield point and to render the bars more elastic at stress levels below the yield points. After stretching, they are stress-relieved by heat treatment to improve the ductility and stress-strain characteristics.

It is noted that reinforcing steel, usually in the form of closely-spaced small bars, is also used in most prestressed concrete members. Such steel provides unstressed reinforcement against secondary stresses and shear stresses.

Grout Materials

The grouting of post-tensioned tendon tubes or ducts may be accomplished with a flowable neat-cement-and-water mixture, or a cement-sand-and-water mixture. (A neat-cement-and-water mixture is one that contains only cement and water, and no additives or admixtures.) As in the case of the cements used in the concrete mixtures for prestressed members, portland cements which conform to ASTM Standard C150, usually type I, II or III, are used for grout mixtures.

PRESTRESSED CONCRETE FABRICATION

Concrete Mix

Most prestressed concrete used in nuclear power plants in cast-in-place and post tensioned. In some cases, however, pre-cast members are used, either of the pre-tensioned or the post-tensioned type.

The production of high quality concrete is a basic requirements for all prestressed concrete applications. The accuracy of batching is essential, as well as thorough mixing. Water content of the mixtures is kept as low as possible to minimize shrinkage and obtain high strength. It has been found that plastic concrete with a slump between 2 and 4 inches contains enough water in the mixture to permit the concrete to be properly placed and compacted, and to avoid honeycomb.

Normally, concrete mixes are trial batched, mixed and laboratory tested before use on the job. Mixes employed should have laboratory strengths 10 to 20% higher than that required by the job specifications.

Particular attention must be paid to the mixing of the concrete. Batches must be mixed in an effective mixer (such as rotating, driven-type truck mixer) at a proper turning rate and for a sufficient time to produce a uniform, homogeneous mixture. If the mixed concrete must be transported to the point of discharge and placement, it must be done with proper equipment in accordance with an established procedure (type of mixing, turning rate of mixer, method and amount of water addition, etc.) to prevent segregation of component materials and to avoid premature set or stiffening. Recommended guidelines are those established in ACI Standard 304 "Recommended Practice for Measuring, Mixing, Transporting and Placing Concrete."

Forms

The types of forms required for the prestressed concrete structure or member depends on the type of structure or configuration of the member. For precast members, forms are designed to be re-used many times to fabricate duplicate parts. For cast-in-place members or structures, standard or modular types of forms are used where possible to minimize form construction and erection time.

For pre-tensioned members, forms are erected and reinforcing steel and steel tendons are placed into the forms. The tendons are then tensioned, then, the concrete is placed in the forms. Internal vibration is usually used to thoroughly consolidate the concrete, eliminate voids, air bubbles, and honeycomb, and to cause the concrete to flow around the reinforcing steel and tendons. Curing of the concrete begins after placement and should provide sufficient moisture to allow the completion of the chemical reactions (cement hydration) which produce strong, durable concrete. Moisture must be contained on the surface of the

concrete during the curing process by means of water soaking or fogging, water-soaked mats, sealing compounds, or polyethylene sheets. The cast member normally remains in the form until the concrete attains the required strength. When the strength and the attendant bond between the concrete and the embedded tendons has been attained, the tendons are cut loose from the tensioning anchors at the ends of the member, and the member is removed from the form system.

Post-tensioned prestressed concrete may be either be precast or cast-in-place as in the case of a reactor building containment structure. In either case, the tendon tubes, ducts, or duct forming devices are positioned within the forms, along with the non-stressed reinforcing steel and other embedments. The concrete is then placed, vibrated (compacted) and cured in the normal manner. The forms are usually removed from these types of structures or members within a day. In the case of a large structure, the tendon ducts may be flushed-out with clean water and blown dry with oil-free air after several days curing time, followed by pulling the tendons into place. For cast-in-place prestressed concrete, tensioning is performed after the concrete has attained the required strength. Pre-cast, post-tensioned members are handled in the same manner, but tensioning is usually performed after the members are erected in their final position and location.

After post-tensioning operations have been completed, a grout mixture is pumped into the tendon ducts, filling all voids and surrounding the tendon steel. The water/cement ratio of the grout must be closely controlled, and the grout must be thoroughly mixed by machine to obtain satisfactory results.

TENSIONING METHODS AND EQUIPMENT

In manufacturing pre-tensioned, pre-cast members, the prestress strand or wires are anchored firmly at one end, and attached by means of strand vises or grips to hydraulic jacking equipment at the other end. The tendons are then stretched to assure equal length and starting tension. Some jacking equipment is designed to stress tendons one-at-a-time, and others to stress tendons as a group (after initial equal tensioning to a nominal value, e.g. 1,000 lbs.). Measurement of the stress imposed on the tendons is usually determined independently by direct force measurement and by elongation measurement of the tendons. Typical specifications require that the difference between the values obtained from the two methods of measurement be less than 5%.

Hydraulic pressure gages, load cells, dynamometers and other devices are used for measuring stressing loads. These devices are regularly calibrated with the calibration performed with the devices installed on the jacking system and with the system in operating condition and mode. The measurement of tendon elongation typically is done within an accuracy of 1% of the theoretical elongation.

After the concrete reaches the specified release strength for detensioning, or transfer of stress to the concrete, multiple strand arrangements are released simultaneously from both ends by flame cutting for gradual stress release and minimal movement of the member. In all detensioning operations, symmetrical release about a member's neutral axis is essential to minimize member shock or movement.

Tendons in post-tensioning systems are handled and anchored differently then pre-tensioned tendons. Wire type post-tensioning systems generally utilize 0.25 in. diameter wires with a guaranteed ultimate tensile strength of 250,000 psi.

Anchorage of most wire tendons is achieved through the use of 0.375 in. diameter button-heads formed on the individual wires by a cold up-setting process.

Stranded type tendons utilize either 0.5 or 0.6 in. diameter 270,000 psi tendons and obtain anchorage through the use of either two-piece or three-piece wedges.

Bar type tendons are comprised of smooth or specially threaded bars with diameters ranging from 1/2 to 1-3/8 in. and with ultimate strengths from 145,000 to 160,000 psi. Bars may be anchored with any of a variety of available anchorage devices, including wedges, compression grips, and threaded ends.

When stressing any of these types of tendons, an initial load of about 10 percent of the full load is applied for absorption of residual slack. During final tensioning, jacking operations are applied simultaneously from both ends of the tendon so that both the jacking force and the measured elongation will compare within 5% of computed values. When the required tension is achieved, the anchors are set, the jacking equipment disconnected, and grouting operations started.

SAFETY MEASURES FOR TENSIONING OPERATIONS

Prestressing inherently involves the use of very high forces, with steel and concrete stressed to a high percentage of their ultimate load. Tendons may be under tension to values as high as 180,000 psi, which represents a tremendous stored energy, and which can convert an anchorage into a deadly missle.

Safety of personnel and equipment can be achieved only by positive efforts, including planning, indoctrination of workmen through a safety program, and enforced safety

requirements at the work site. Rules must be established including such items as the following:

- Before tensioning, all personnel not required to perform the tensioning should be warned with an audible and visual signal to leave the immediate area.
- Jacks should be secured to prevent lateral or longitudinal motion in the case of tendon failure.
- All personnel should be restricted from the areas at the end of the member or tensioning bed directly in line with the tendon being tensioned.
- Elongation measurements or tendons being tensioned should be taken by personnel from the side by jigs or templates or from behind shields, and not from above the tendons.
- Eye protection should be work by personnel performing wedging and anchoring operations to preclude injury from flying pieces of steel.

INSPECTION AND TESTING

Scope

Inspection and testing operations are usually required for all elements entering into the complete prestressed concrete system when used on nuclear power plant projects. Complete and accurate records must be maintained for the engineer, owner, inspection agency, and governmental regulatory bodies.

Materials are generally purchased to conform to applicable ASTM standard requirements. This applies to both the concrete materials, reinforcing steel, tendons, and tendon anchorage materials. When required by the purchase order, manufacturers furnish material test reports and

certifications, which should be examined for completeness and acceptability by the cognizant inspector. These manufacturers' test reports should be identified with bins, cars, heats, reels or other specific lots. A records control system is usually required and used that identifies the specific materials that were used in fabricating each prestressed member.

The major activities in fabricating prestressed concrete members or structures which are subjected to inspection and test are shown in Table 29-6-1.

Table 29-6-1

Activities Subject to Inspection and Test

Pre-tensioned	Post-tensioned
Setting of forms	Setting of forms
Installation of reinforcing steel	Installation of reinforcing steel
Installation of inserts	Installation of tendon ducts
Installation of tendons	Concreting operations
Anchoring and pre-tensioning of tendons	Concrete curing and form removal
Concreting operations	Installation and Post-tensioning of tendons in ducts
Concrete curing and form removal	Grouting operations
Detensioning/stress transfer	

Inspection of Setting of Forms

Attributes typically inspected with respect to setting of forms are as follows:

- Forms adequately braced, stiffened, anchored and aligned to produce members or structures within the limits of dimensional tolerances.
- Bulkheads, spacers and templates conformance dimensionally with drawing requirements.

- Form joints smooth and tightly fit to prevent leakage of cement paste.
- All slots and holes in the forms plugged neatly so that the finished surface has a workmanlike appearance.
- Forms and beds thoroughly cleaned after each use.
- Forms and beds properly coated with form-release compound.

Inspection of Reinforcing Steel Bars and Mesh

Attributes typically inspected with respect to installation of reinforcing steel bars and mesh are as follows:

- Bars and mesh fabricated in the configuration shown on drawings and installed within specified tolerances.
- Bars and mesh supported and secured by chairs, blocking, and ties to the beds or forms to maintain its position during concrete placement and vibration.
- The ends of tie wires used to hold bars or mesh bent into the structure to provide maximum concrete cover.
- Welding on reinforcing bars or mesh permitted only as described by job specifications. (Normally not permitted.)
- Bars, which extend out of the member or structure to provide structural connection for cast-in-place connections, extend as shown on applicable drawing, within specified tolerances.

Inspection of Installation of Inserts and Tendon Ducts

Attributes typically inspected with respect to installation of inserts and tendon ducts are as follows:

- Inserts, such as anchor bolts, bearing plates and lifting devices, located accurately, as shown on the drawings.

- Tendon ducts located as shown on the drawings in a smooth path free from kinks and without interference from reinforcing steel components.
- All embedded items free from deleterious substances that will reduce bond with the concrete, such as form release agents or other contaminants.

Inspection of Installation of Tendons in Pre-tensioned Members

Attributes typically inspected with respect to installation of tendons in pretensioned members are as follows:

- Strands carefully threaded through bulkheads or cages of reinforcing steel to preclude damage from kinks or entanglement.
- Cutting of strand between the vise and the reel, and the nicked segment discarded. (Note: Strand vises, which are used to grip and pull the strands into position, notch or nick the wires at the grip points.)

Inspection of Anchoring and Pre-tensioning of Tendons

Attributes typically inspected with respect to anchoring and pre-tensioning of tendons are as follows:

- Anchorage devices exhibit proper alignment and attachment to the strand, prior to the application of stress.
- Uniform initial tensioning force applied to each strand to result in a final, uniform stress condition in all strands.
- Initial load applied with either pressure jacks or fence stretchers and measured during application. The usual tolerance for initial load is $\pm$50 lbs. or 2%, whichever is larger, but this allowance may vary, depending on the particular job specification.

- Initial load held momentarily while reference marks are applied to the strands for measuring elongation and slippage. The inspector should observe the application of these marks.
- Application and measurement of the final tension force using calibrated gages or dynamometer. Flongation of the strand is measured and recorded, using the reference marks and taken to the nearest 1/4 inch.

Inspection of Concreting Operations

Attributes typically inspected with respect to concreting operations are as follows:

- Batching, mixing, transportation and discharge of the concrete into the forms comply with specification.
- Each batch of concrete delivered to the forms placed as nearly as possible, in final position, adjacent to the preceding and following batch and the whole mass consolidated by vibration with as little lateral shifting as possible.
- Vibration performed to produce a uniformly dense and plastic mass, with the following considerations:
  - Vibrators used for compaction only, and not for moving concrete horizontally along the forms.
  - Spacing of points of vibration such that zones influence overlap for both horizontal and vertical operation of vibrators.
  - For concrete deposited in layers, vibrator inserted vertically and allowed to sink due to its own weight to the bottom of the layer and slowly withdrawn. For succeeding layers, vibrator penetrates the surface of the preceeding layers.
  - Concrete testing operations including sampling, cylinder preparation, slump tests, air content

tests, and compressive strength tests, comply with specifications.

Inspection of Concrete Curing and Form Removal

Attributes typically inspected with respect to concrete curing and form removal are as follows:

- Concrete curing procedures started immediately following the initial set or completion of surface finishing.
- Concrete kept moist to prevent surface cracks due to rapid loss of water from evaporation. (Moisture may be retained by sprinkling or ponding with water, using moisture-retaining covers, or by a liquid seal-coat of a thin water-impervious membrane.)
- Test cylinders of concrete cured, as nearly as possible, in the same manner as the member or structure which the sample represents.
- Forms loosened and removed carefully to preclude damage to the concrete surface.
- For pre-tensioned members, forms loosened or removed before de-tensioning takes place.

Inspection of De-tensioning/Stress Transfer of Pre-tensioned Tendons

Attributes typically inspected with respect to de-tensioning or stress transfer of pre-tensioned tendons are as follows:

- Stress transfer to pretensioned members effected only after specified concrete transfer strength has been attained, as indicated by compressive strength cylinder test results. (Normally, minimum concrete transfer strength is 3,000 psi for typical wet-mix concrete applications.)

- De-tensioning proceeds by gradually releasing the tensioning pressure on the strands, maintaining symmetrical forces about the vertical axis, and minimizing sudden or shock load on the concrete member.
- Multiple strand de-tensioning performed by releasing the strands simultaneously and gradually, by hydraulic jacking.
- Single strand detensioning performed by heat cutting the strands with a low-oxygen flame or other specified method.

Inspection of Installation and Post-tensioning of Tendons in Ducts

Attributes typically inspected with respect to installation and post-tensioning of tendons in ducts are as follows:

- Tendons are pulled through the ducts and anchored at both ends. Anchorages check to verify proper alignment and secure condition.
- Tensioning begins after the concrete has attained the required transfer strength, as determined by compressive strength test results.
- Tendons tensioned in accordance with a specified sequence as determined by the design in order to keep stresses with predetermined limits of symmetry about the axes of the member or structure.
- An initial load applied to each tendon, reference marks applied, and the full load applied. Stress measurements taken by both elongation and gage readings, and checked within 5% of theoretical values.

Inspection of Grouting Operations

Attributes typically inspected with respect to grouting operations are as follows:

- Ducts satisfactorily clean before the grouting operation begins. (Following post-tensioning, tendon ducts are usually flushed with clean water to remove any tendon-lubrication materials or other foreign matter, and blown free from water with clean, compressed air.)
- Grout mixture batched accurately and mixed according to the designated design mix.
- Grouting Techniques including grout pumped into the ducts, toward open vents, under moderate pressure until all entrapped air is forced out the open vent or vents. A steady stream of grout from the vents indicates that the entire duct is filled. At that point, the discharge vents closed, the pressure raised to a minimum of 50 psi and held for a minimum of one minute, after which the injection point is plugged to prevent any loss of grout from the pressurized duct.

EXERCISES

1. State the purpose of items associated with prestressed concrete by completing the Purpose column of Table 29-6-2.

Table 29-6-2

Items Associated with Prestressed Concrete

Item	Purpose
tendon	
bearing plate	
tendon duct	
grout	
form	
vibrator	
water soaked mat	
hydraulic jack	
load cell	
material test report	
compression test sample	

2. Describe tensioning and de-tensioning of a pre-tensioned concrete member by completing the Description column of Table 29-6-3.

Table 29-6-3

Pre-Tensioned Concrete Member

Operational Step	Description of Step
Form Setting	
Tendon Installation	
Pre-tensioning of Tendons	
Concreting	
Curing and Form Removal	
De-Tensioning	

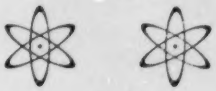
3. Describe tensioning and de-tensioning of a post-tensioned concrete member by completing the Description column of Table 29-6-4.

Table 29-6-4

Post-Tensioned Concrete Member

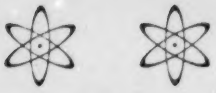
Operational Step	Description of Step
Form Setting	
Tendon Duct Setting	
Concreting	
Curing and Form Removal	
Tendon Installation	
Post-Tensioning	
Grouting	

4. A section of a post-tensioned prestressed concrete wall is to be constructed. The drawings of the wall indicate that the wall is reinforced with deformed steel bars and has embedded steel tubes for tendon ducts. Prepare an inspection check-list to cover all construction operations from the setting through final grouting. Submit the inspection check list to the instructor.



MATERIALS

None.



PROCEDURES

1. Tour concrete precasting plant and observe pre-tensioning operations.
2. Tour construction site and observe pre-tensioning or post-tensioning of prestressed concrete members.

DATA TABLE

None.

REFERENCE MATERIALS

Abeles, P.W., Principles and Practice of Prestressed Concrete, Corsby Lockwood and Son, Ltd., London, 1949.

Guyon, Y., Prestressed Concrete, John Wiley and Sons, Inc., New York, 1953.

Leonhardt, Fritz, Prestressed Concrete Design and Construction, Wilhelm Ernst and Sohn, Berlin, 1964.

Libby, James R., Modern Prestressed Concrete, Van Nostrand Reinhold Co., New York, 1971.

Gerwick, Ben C., Jr., Construction of Prestressed Concrete Structures, Wiley-Interscience, New York, 1971.

TEST

1. State the purpose of concrete prestressing.

2. Name three basic methods for prestressing concrete members and briefly describe how each is accomplished.
   a.

   b.

   c.

3. Describe the role of standards in ensuring quality concrete materials.

4. Name three types of steel tendons used in prestressed concrete applications.

5. State the purpose of tendon ducts.

6. Describe how pre-tensioning of a concrete member is accomplished beginning with forms in place and ending with de-tensioning; include type of tendon, tendon installation, method of tensioning, use of reference marks, and release of tension.

7. Describe how post-tensioning of a concrete member is accomplished beginning with forms in place and ending

with de-tensioning; include type of tendon, tendon installation, method of tensioning, use of reference marks, and release of tension.

8. Briefly describe inspection of the following operations and give two inspection attributes for each.
   a. setting of forms

   b. concreting operation

   c. grouting operations

   d. tensioning of tendons